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Modeling the Interacting Detonation Fronts Observed by Low Energy Radiography

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Abstract

We have completed a series of experiments in which we made radiographs of interacting detonation fronts in a high explosive. Although the fronts and interactions were observed, the experimental data were insufficient to distinguish between two computer models which we employed to simulate the experiments.

Introduction

Recently we conducted a series of experiments of two types in which we employed low energy flash x-rays to obtain multi-frame radiographs of interacting detonation fronts in an HMX-based high explosive (HE). In the first type of experiment (Fig. 1.), a one-inch diameter cylinder of HE was detonated at the center of one end, and we observed the extended interaction zone of the detonation front after it was split by a half inch diameter imbedded plastic sphere. In the second type (Fig. 1.), a one-inch thick slab of HE was detonated at two points separated by 2 cm simultaneously at one end, and we observed the interaction of the two fronts as well as the propagation of each resultant shock wave through the products of the other detonation. Each type of experiment was conducted twice, and in each case radiographs were taken at three separate times during the burn.

Information from such experiments can improve our knowledge of HE detonation. In particular, it can provide information relevant to the degree that detonation velocity increases in the region where detonation fronts interact due to the increased pressure there, and it can provide information relevant to the equation of state of the detonation products from the speed of propagation of the shocks through the products.

We have tested two detonation models against the observations. The first is a "programmed burn" model in which one assumes that any element of the HE releases its energy according to two criteria. The energy release occurs at a time equal to the distance of the element from the detonation point divided by an assumed detonation velocity or at an earlier time if the pressure within the element exceeds a certain amount. In both cases the energy release can occurs over a short time period according to criteria involving element size and pressure values. The second model is a "reactive flow" model in which the HE chemical reaction and energy release rates are modeled as they depend upon time, density, and temperature.[1] This way of treating the detonation attempts to model some of the actual physics and chemistry involved, which is treated phenomenologically in programmed burn. Reactive flow determines the detonation speed as a consequence of the properties of the HE and the current conditions of the medium. Both models are imbedded in hydrodynamics codes which handle shock propagation as influenced by the equation of state of the medium.

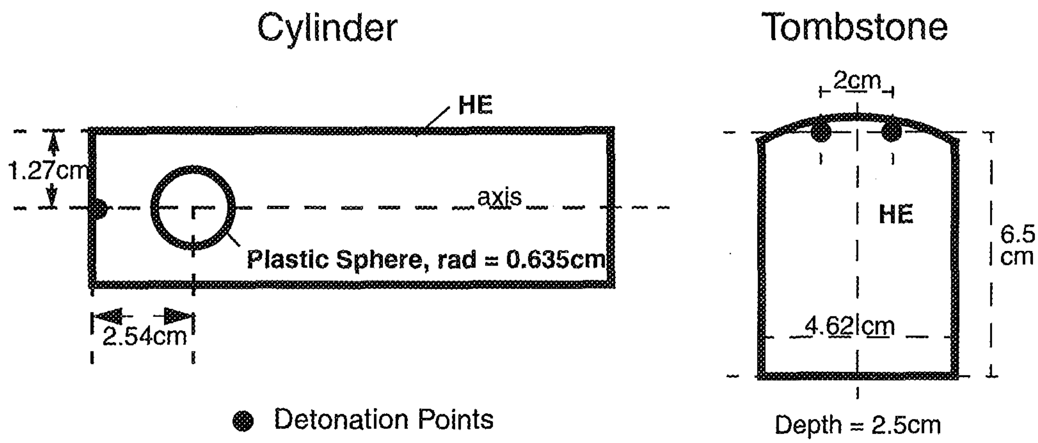

Fig. 1. The two types of experiments in which radiographs were made of interacting detonation fronts. The detonation front in the cylinder interacts with itself after progressing around a plastic sphere. In the tombstone two separately and simultaneously produced detonation fronts interact.

Experimental Results

The experiments employed three Scandiflash 450 x-ray sources. These machines produce a bremstrahlung spectrum that cuts off at 450 KeV with a strong line at about 60 KeV. The bremstrahlung and the line contribute about equally to exposing the film in these experiments. The sources were 7 ft. from the high-explosive objects, and the film was 2 ft. behind the objects. The x-rays were, to a degree, collimated, and the layers of film were protected by plastic shields.

Fig. 2. shows one of the six frames for the first type of experiment. The detonation here has just passed all of the way around the cylinder and has begun converging upon itself on the far side. Fig. 3 shows one of the frames for the second type of experiment. The two detonation fronts may be seen, as well as the two shock fronts following detonation which are each proceeding through the detonation products from the other detonation.

Photometric analysis of the radiographs indicates that about two out of three of the photons causing film exposure were scattered background photons. Additionally, film response was somewhat mottled (random variations in response at a scale several times grain spacing). These circumstances limited the contrast and our ability to accurately determine the positions of detonation and shock fronts, in particular when tomography is applied to the first type of experiment (cylindrically symmetric).

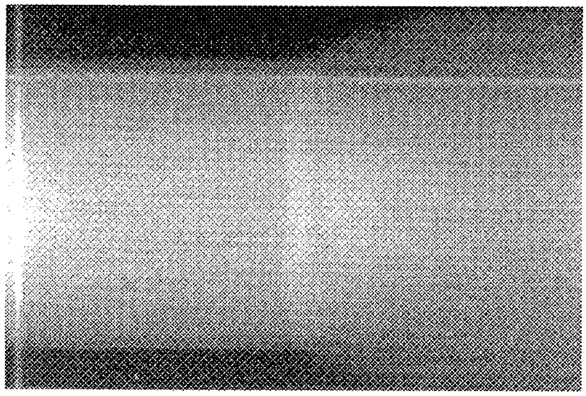

Fig. 2. One radiograph from the first type of experiment (cylinder). The detonation front (vertical feature near center) has just passed around the plastic ball moving from right to left and has begun to interact with itself. No attempt has been made to enhance contrast here.

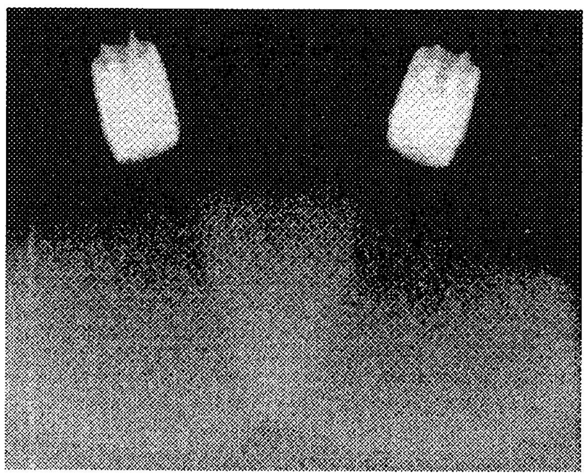

Fig. 3. One radiograph from the second type of experiment (tombstone). The two light objects are the detonators. The detonation fronts are apparent near the bottom, and the shock waves moving through portions of the HE that have already detonated are in the mid to lower center. Contrast has been enhanced to show the detonation fronts, and, as a consequence, no features are seen in the upper portion of the radiograph except for the detonators.

Model Comparisons

Fig. 4 shows a comparison of the results shown in Fig. 2 with the results of 2D hydrodynamics simulations using both the programmed-burn and reactive-flow detonation models. It may be seen that the quality of the experimental data is insufficient to distinguish between the two models.

Fig. 5 shows a comparison between a visual determination of the positions of the detonation and shock fronts shown in Fig. 3 with a 3D hydrodynamics calculation using the programmed-burn model for detonation of the high explosive. The agreement is as good as can be expected considering the experimental uncertainty.

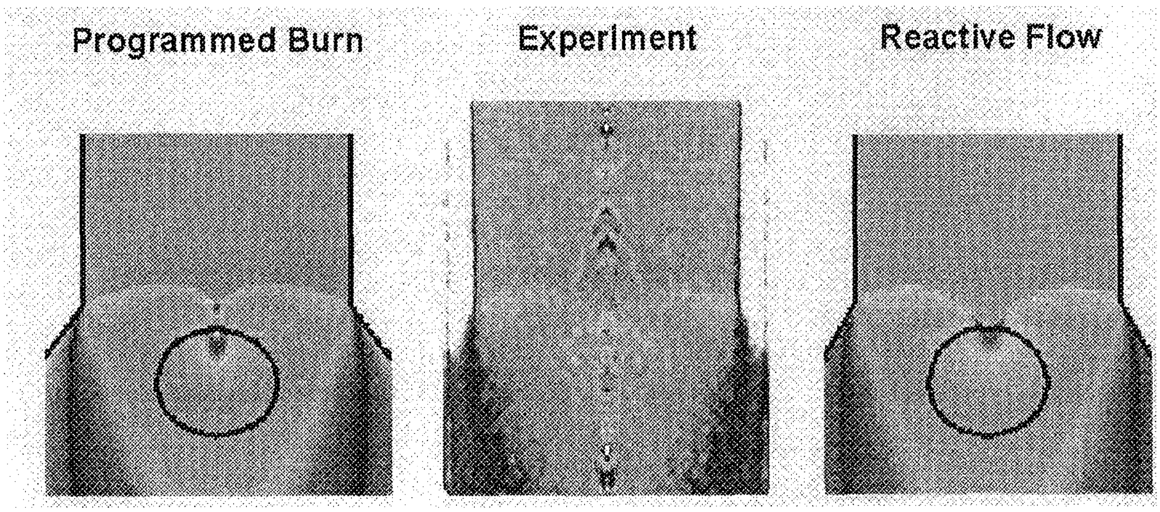

Fig. 4. Cuts, showing density, through the axis in the cylinder experiment at the time of the radiograph shown in Fig 2. The detonation is moving upward here. The center picture is a tomographic reconstruction from that radiograph. The quality of the data, as evidenced by the reconstruction, is insufficient to judge the accuracy of either model whose results are shown on the left and right. In the model results, the material boundaries have been drawn in.

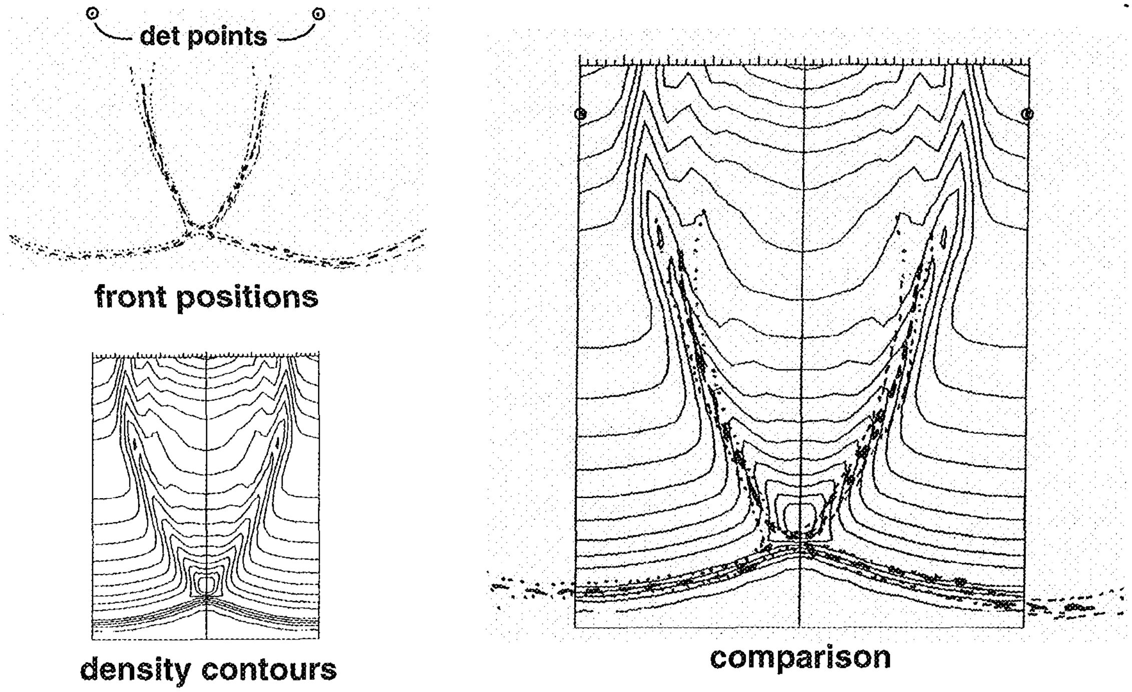

Fig. 5. A crude comparison of the experimental results shown in Fig. 3 with a 3D hydrodynamics calculation using the programmed-burn model. The experimental results are represented by an "eyeball" estimate of the positions of the detonation and shock fronts, while the calculation is represented by contours of density taken along the mid plane that contains the two detonation points. The fronts should be at about the location of maximum calculated density gradient, and that is seen to be approximately true.

Acknowledgment

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Reference

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Keywords

Detonation fronts, modeling, reactive flow, radiography